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CHEMICAL EXTRACTION AS AN INDEX OF BIOAVAILABILITY OF PHOSPHATE--ETC(U)
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CHEMICAL EXTRACTION AS AN INDEX OF
BIOAVAILABILITY OF PHOSPHATE
IN LAKE ERIE BASIN SUSPENDED SEDIMENTS

FINAL PROJECT REPORT
AGRONOMY DEPARTMENT
OHIO AGRICULTURAL RESEARCH AND DEVELOPMENT CENTER
WOOSTER, OHIO 44691

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Terry J. Logan
Project Leader

January 1978

LAKE ERIE WASTEWATER MANAGEMENT STUDY
U.S. ARMY CORPS OF ENGINEERS
BUFFALO DISTRICT, BUFFALO, N.Y.

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INTRODUCTION

The role of phosphorus in accelerated eutrophication of Lake Erie and other areas in the Great Lakes Drainage Basin has been recognized and documented in recent years. Studies by LEWMS and PLUARG have shown that a major part of the total phosphorus load entering the lakes from tributary drainage is in the form of particulate-P. While it is readily accepted that soluble inorganic-P in drainage water is available to algae and other aquatic vegetation, the bioavailability of sediment-bound phosphate is largely unknown. As a result, one is faced with two extreme scenarios: a) only the soluble inorganic-P is bioavailable and b) all sources of P including sediment-P are available. The first scenario is supported by the findings in New York where soluble inorganic-P was shown to be the dominant form of stream-transported phosphate in stimulating growth of algae (Porter, 1975). On the other hand, Golterman (1977) found that sediment-P in shallow polder lakes in Holland would maintain highly eutrophic conditions even if all external P sources were removed. Recent work by Allan and Williams (1978) demonstrated the importance of biologically available sediment-P in fairly shallow Canadian prairie lakes.

The importance of sediment as a source of P for algae is governed by a number of factors. Streams which carry a low sediment load, and/or sediment of coarse-texture and stream-bank origin will have most of its biologically available P as soluble inorganic-P as a consequence of the lower P content of coarse sediment (Williams *et al.*, 1976). Consideration must also be given to physical lake dynamics. Stream sediments which settle rapidly into deep lakes will only be positionally

available to algae in the photic zone for short periods as in the central and eastern basins of Lake Erie, thereby minimizing the significance of sediment-P as a source of biologically available phosphorus. In contrast, we have the situation where streams carry a high load of fine-grained sediment into shallow lakes, a situation similar to that in the western basin of Lake Erie. In this instance, factors which serve to increase the importance of sediment-P are: the high percentage of the total phosphorus load as sediment-P, the higher content of P in clay-sized sediment, and the longer period in which this suspended sediment load is positionally available to algae in the photic zone.

Chemical extraction procedures to estimate bioavailability of sediment-P from tributary sources must take into account the conditions under which algae obtain P from sediment. Algae can derive some P from sediment in the photic zone for short periods and under aerobic conditions. In addition, available-P is derived from bottom sediments during anoxic regeneration and subsequent lake inversion, a markedly different chemical environment than exists in the photic zone. While much of the P regeneration is from decomposed algal biomass, sediment-P is also released under anoxic conditions. As a result of this dichotomy, bioavailable sediment-P will be viewed here in two ways: a) positionally available, to represent short-term release of P to algae in surface waters, and b) total potentially available, to represent maximum P which can be released over time by all mechanisms. Chemical extraction procedures to estimate sediment-P bioavailability will be discussed in the context of this concept.

In the following sections, discussion will include:

- 1) Differences in characteristics of soils, suspended sediments and bottom sediments
- 2) Chemical extraction procedures to estimate sediment bioavailability and their relation to sediment properties
- 3) Estimates of phosphorus bioavailability of Lake Erie sediments
- 4) Kinetics of desorption and chemical exchange of sediment-P.

1. Some contrasting characteristics of soils and sediments

There is a growing body of research on chemical extraction procedures to estimate bioavailable sediment-P (BSP). Much of the early work was done on soils, with more recent studies on lake and stream sediments. Differences in these studies can be attributed, in part, to differences in the biological and physicochemical characteristics of soils and sediments. A major treatment of the subject is not intended here. However, several major differences between soils and sediments are apparent. First, because of their fluvial transport, sediments are unstructured and generally more fine-grained than the soils from which they were derived. They tend to be enriched in organic matter, and this together with their fine-grained nature results in an enrichment of sediments with phosphate, hydrous oxides of iron and some aluminum, and, in some sediments with carbonates. Suspended stream sediments behave much like their soil precursors except for their P enrichment (Green et al.,

1978). Bottom sediments, on the other hand, in both lakes and streams may be subjected to long periods of anoxia with subsequent reduction and solubilization of iron (Patrick and Mahapatra, 1968). Phosphate release from suspended sediments is much more similar to that from soil than from bottom sediments. Discussion of chemical extraction of sediment-P must consider these significant differences.

2. Chemical extraction procedures to estimate BSP

Any chemical extraction procedure to estimate soil or sediment bioavailability must have the following attributes:

1. Must correlate with biouptake
2. Should be applicable to a wide range of soils or sediments
3. Should be relatively easy to perform and the results should be reproducible.

Early work in soil science was concerned with development of soil test procedures, i.e. chemical extractants to estimate availability of soil-P to agronomic crops. Most of the procedures did one or more of the following:

1. Removed soluble-P held in soil pores
2. Used another anion to exchange with some of the $H_2PO_4^-$ adsorbed to soil surfaces
3. Dissolved or hydrolyzed part of the more labile soil-P complex.

Many of the procedures used, in fact, do all three. In the Lake Erie Basin, today, two soil testing procedures for plant-available phosphate

are used: 0.5 M NaHCO_3 (Olsen *et al.*, 1954) and the Bray P1 (0.03 M NH_4F + 0.025 M HCl) (Bray and Kurtz, 1945). The Bray procedure is used in all the U.S. Lake Erie Basin states and the Olsen test in Ontario. These tests have also been used to characterize sediment-P (Romkens and Nelson, 1974; McCallister and Logan, 1978).

Workers at Wisconsin (Chang and Jackson, 1957) began to look at sequential chemical extraction to characterize soil-P. Their original theory was that phosphorus in soil occurred as discrete chemical forms which could be selectively removed by sequential chemical extraction. They proposed the following scheme:

<u>Chemical form</u>	<u>Extractant</u> (in sequence)
Saloid-bound P	1 N NH_4Cl
Aluminum-P	0.5 M NH_4F
Iron-P	1 N NaOH
Occluded-P	citrate-dithionite-bicarbonate
Apatite-P	1 N HCl

This theory of discrete P forms in soil has been questioned by Bache (1963, 1964), Bauwin and Tyner (1957) and others. A more prevalent view today is that much of the inorganic-P in soil is chemisorbed to a number of reactive surfaces including iron and aluminum oxides and hydrous oxides, amorphous aluminosilicates and carbonates, or occluded in the matrices of a number of soil mineral forms. Probably only small amounts of apatite in some soils are representative of the discrete P form envisaged by Chang and Jackson (1957). Nevertheless, their scheme for chemical fractionation of soil-P proved to be highly useful in looking at relative differences between soils, and their work proved to be the

stimulus for much subsequent research in this area (Logan and McLean, 1973; Fiskell and Spencer, 1964; Robertson et al., 1966).

While the original fractionation schemes were designed to study the effects of soil genesis on soil-P forms, it was quickly adopted by soil chemists as a tool for the study of phosphorus fertilizer reactions in soil, and, more recently, as an indicator of soil potential for water pollution (Reddy et al., 1978). The utility of these schemes is based not on their ability to extract discrete P forms, but because the scheme uses sequential extraction, and because the order of the sequence is from least severe and most selective to most severe and least selective. If one accepts the fact that P is bound to many different surfaces in soil with varying binding forces, and that the P which is held on the weakest sites will be the most environmentally reactive, then this type of sequential extraction, in effect, partitions soil and sediment phosphate on the basis of binding strength.

Major developments in the basic scheme proposed by Chang and Jackson (1957) have been accomplished by Williams and Walker (1969a and b); Williams et al. (1967); Williams et al. (1971a and b); Allan and Williams (1978) for soils and lake sediments. Syers et al. (1972) encountered problems with the NH_4F extractant for aluminum-P and dropped it in favor of NaOH as a single extractant for the combined iron- and aluminum-bound P fractions. Most workers have also dropped the NH_4Cl extraction because the amount of P extracted is very low compared to other fractions. More recently, Williams (Williams et al., 1976; Allan and Williams, 1978) has simplified the scheme for lake sediments even further. He proposes two inorganic sediment-P fractions: non-apatite phosphorus (NAIP) extracted

by citrate-dithionite-bicarbonate (CDB), and apatite-P extracted by HCl or H₂SO₄. Allan and Williams (1978) have proposed that the NAII' fraction be considered bioavailable, based on correlations of CDB extraction with the NTA extraction of Golterman (1976) which was found to estimate sediment-P availability to Scenedesmus.

Few studies are available which give direct correlation between algal P uptake from sediment and chemical extraction. The work of Golterman (1976) has already been mentioned. Sagher et al., (1975) found that 0.1 N NaOH extractable P was highly correlated with P uptake by P-deficient algae when sediment-P was the only phosphate source. More recently, Corey (personal communication) used the same algal assay system as Sagher et al., (1975) and found high correlation of algal extractable P with sediment-P extracted by aluminum-saturated exchange resin. Cowen and Lee (1976) found that amounts of P available in New York urban runoff sediment to Selenastrum were similar to that extracted by anion exchange. Correlation with anion exchange extraction was better than with 0.1 N NaOH extraction, the base extraction significantly over-estimating bioavailability. Their data will be discussed further in another section.

Another method for estimating BSP involves the thermodynamic response of sediment surfaces to reactive inorganic phosphate. Figure 1 gives an idealized isotherm for adsorption-desorption of inorganic P by soil or sediment.

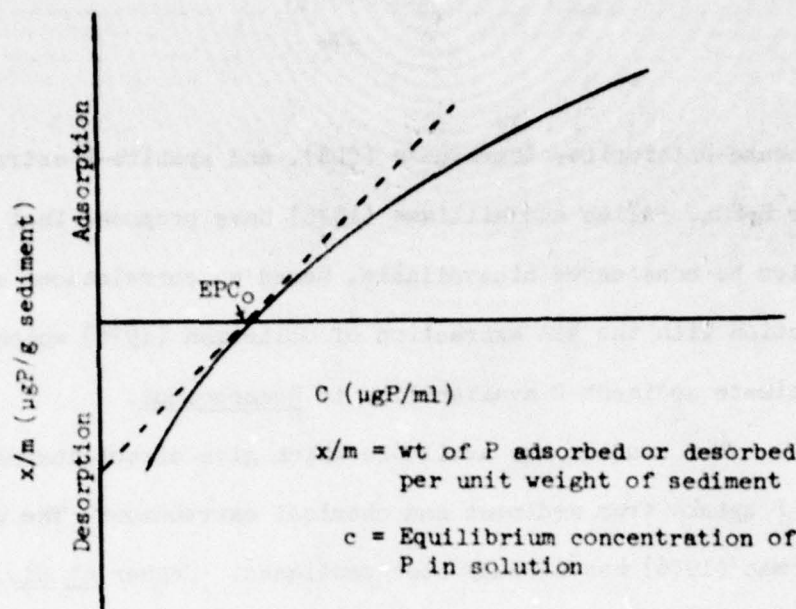


Figure 1. Adsorption/desorption curve (idealized) for soil or sediment.

Net adsorption occurs when equilibrium P concentration exceeds EPC_0 , and net desorption when $C < EPC_0$. EPC_0 , the equilibrium P concentration at which P is neither adsorbed nor desorbed is a useful parameter for predicting soluble inorganic P concentrations in equilibrium with suspended sediment (Taylor and Kunishi, 1971; McCallister and Logan, 1978; Green *et al.*, 1978; Ryden *et al.*, 1972). Of equal importance, however, is the buffer capacity of the sediment, i.e. the amount of P that must be adsorbed or desorbed by unit mass of sediment to produce a unit change in soluble inorganic P concentration. Taylor and Kunishi (1971) define BSP as the amount of P that must be desorbed by sediment to reduce equilibrium P concentration from EPC_0 down to some arbitrary value at which P is limiting to algae growth. This value can be obtained as the slope of

the curve in Figure 1 (dotted line). Sediment buffer capacity is a function of such factors as surface area (related to clay content of sediment), reactive surfaces on sediment particle and amount of labile P already adsorbed. Bouldin used a similar procedure to estimate BSP for tributary drainage into New York lakes (Porter, 1975). Procedures of this kind usually involve short-term incubation (< 6 days) and probably represent the most biologically available sediment-P, but, at the same time, probably underestimates total potential BSP.

3. Kinetics of exchange and desorption of sediment-P

Procedures discussed previously in this report deal with the capacity of sediment to supply inorganic P to organisms. Little work has been done, however, on the rate of release of sediment-P. Isotopic exchange rates using ^{32}P were measured in soils (Amer *et al.*, 1955) and sediments (Li *et al.*, 1972). They showed that exchange involved at least three different reactions, the fastest coming to completion in 15 minutes and the slowest continuing for at least 72 hours. Both studies showed that a large percentage of the exchangeable P was exchanged during the initial rapid reaction. Rajan and Fox (1975) demonstrated that P adsorption by soil showed a fast and slow reaction, and that desorption of P occurred at a rate similar to the slow adsorption reaction. Ryden *et al.* (1977) have attributed the fast exchange reaction to a physical adsorption of H_2PO_4^- anions by positively charged colloid surfaces, while the slow reaction may involve precipitation-dissolution of metal-phosphate complexes and diffusion of phosphate ions from chemically bound sites to more labile positions. After desorption

of the physically sorbed labile P, the slow desorption of phosphate may determine the rate at which algae can obtain inorganic P from sediment.

Almost all desorption studies (Ryden et al., 1972; McCallister and Logan, 1978; Green et al., 1978) have involved batch equilibration of soil or sediment with P-free distilled water or dilute electrolyte. While this information is useful in characterizing relative ability of sediments to supply P, they shed little light on the kinetics of P release in the presence of a continuous sink, i.e. algae.

4. Estimates of bioavailability of sediment-P in Lake Erie Basin suspended sediments and other sediments

Interest in sediment-P bioavailability has increased in the last decade as research into the causes of cultural eutrophication in lakes has increased. Since 1970, a number of studies, using the many different procedures discussed previously, have been used to estimate BSP. This is usually expressed as ugP/g sediment or as a percentage of the total sediment-P or total inorganic-P. In this section, some of the results will be compared, and wherever possible, common units will be used.

Sagher et al., (1975) studied algal uptake of sediment-P from several Wisconsin lakes and correlated uptake with chemical extraction. Highest correlation was obtained with 0.1 N NaOH extraction. They found that > 80% of total sediment inorganic-P was available to algae for noncalcareous sediments. Williams et al., (1971b) had shown previously that NaOH-P would extract most of the inorganic-P in noncalcareous Wisconsin lake sediments. In calcareous sediments, 50-70% of the sediment inorganic-P was found to be bioavailable (Sagher et al., 1975).

Coven and Lee (1976) studied P bioavailability of urban runoff and stream sediments in Wisconsin and New York, using algal incubation techniques as well as chemical and resin extraction. Madison, Wisconsin urban runoff sediment gave BSP values of ~ 30% of total P as measured by either incubation with Selenastrum, resin extraction or NaOH extraction, with a range of 2-55% depending on individual sample or method used. Resin extraction gave somewhat lower values than either Selenastrum bioassay or base extraction.

In New York urban runoff sediments, resin and base extraction gave similar results, 16 and 22% of total sediment-P, respectively, with a range of 1-37% depending on individual sample and method employed. Selenastrum bioassay, however, was < 9%. Genesee River sediments gave a value of 6% with Selenastrum bioassay, while resin extraction gave 6 to 31%. The authors attributed the lower bioassay value to competition for P by native algal species in the sample during incubation. One must conclude from their work that while resin or base extraction gives reasonable estimates of BSP for Wisconsin sediments, these procedures will overestimate BSP for New York sediments.

Recently, Nelson (1978) studied BSP of suspended sediments in the Black Creek watershed in Indiana. This 5000 hectare watershed is located in the western Maumee River Basin, and is typical of much of the rural land use and geochemistry of western Ohio and north-eastern Indiana. They used Selenastrum bioassay and sequential chemical extraction to estimate BSP. Their chemical extraction procedure included 0.5 M NH_4F prior to 0.1 M NaOH, and as such, represents the original scheme developed by Chang and Jackson (1957). It is the opinion of this author based on

unpublished work in our laboratory that a substantial portion of the NH_4F -extractable P would be extracted by NaOH alone. The sum of these two fractions accounted for between 71 and 81% of the sediment inorganic P extracted by Selenastrum. This represented between 19 and 29% of the total sediment inorganic P. Nelson (1978) also found that sediments from agricultural drainage areas had lower BSP than from an agricultural area influenced by P input from a small village. The Maumee River at the outlet of Black Creek was somewhat higher in BSP than the other areas.

While it has been recognized (Williams et al., 1976) that fine-grained sediments are often higher in total P and organic matter than coarser sediments, little data is available on P bioavailability of different sized sediment fractions. Armstrong et al. (1977) have reported on preliminary results of chemical extraction of sediment-P for different sized sediment fractions in Great Lakes tributaries (Genesee R., New York; Maumee R., Ohio; Grand R., Michigan; Menomonee R., Wisconsin; Nemadji R., Minnesota). Maumee and Nemadji sediments were highest in total clay, the Genesee highest in silt (2-20 μ) and the Menomonee had the highest percentage in the size range > 20 μ . In most cases, total-P and resin extractable-P or NaOH extractable-P as percent of total P increased as particle size decreased. In all size ranges, Maumee sediment had the highest bioavailability (as estimated by either resin or NaOH extraction) and the Nemadji the lowest. Genesee and Menomonee sediments were intermediate and similar. BSP (as percent of total sediment-P) ranged from 5-48%.

OBJECTIVES OF THE STUDY

1. To characterize the phosphorus contained in suspended sediments from streams draining into Lake Erie.
2. To study the differences in suspended sediment phosphorus entering Lake Erie in streams from different drainage basins.
3. To estimate the bioavailability of phosphorus to aquatic plants from suspended sediments in streams draining into Lake Erie.

METHODS

1. Sample Collection

During the period March through July, 1977, a total of 66 samples were collected from 36 tributary locations in the Lake Erie drainage basin on the U.S. side. A summary of the sites, tributaries, sampling dates, etc. are given in Table 1. Six major tributaries in Michigan and two smaller streams with drainage areas ranging from 20 to 1042 mi² (52-2698 km²) were sampled between March 5 and May 16. In Ohio, eight major tributaries and ten smaller streams ranging in drainage area from 0.3 to 6330 mi² (0.8-16395 km²) were sampled between March 10 and July 7. In New York four creeks ranging from 10 to 37 mi² (26-96 km²) were sampled on April 23.

The sites were arbitrarily separated into four groups:

1. Michigan streams
2. Maumee-Portage-Sandusky-Huron river basins
3. Eastern Ohio streams
4. New York streams

This division allows some separation on the basis of land use and geochemistry.

Samples provided were either part of an ongoing monitoring program or were taken for this study. Some samples were pumped while others were grab sampled. Drs. Steve Yaksich, U.S. Army Corps of Engineers Buffalo District and David Baker, River Laboratory, Heidelberg College, Tiffin, Ohio provided most of the samples. Most samples were taken during the period of medium to high flow (Table 1) and so represent the period of maximum sediment transport.

Sample sites are located in Figure 2 by numbers which correspond to those in Table 1.

2. Handling and Storage of Samples

A four-liter sample of sediment suspension was collected. Upon delivery, each sample was vigorously shaken to disperse the sediment and two 250-ml aliquots were taken (Figure 3). One 250-ml aliquot was filtered through a 1.0 μ m Nucleopore filter and the filtrate stored in polyethylene bottles and frozen. The second 250-ml aliquot was left unfiltered and stored at 4°C in polyethylene bottles. The remaining 3.5 liters was allowed to stand overnight at 4°C for sediment to settle.

After settling, the supernatant was siphoned out into another container. The sediment was shaken and transferred to a smaller container and left to settle. After most of the supernatant was poured out, the sediment was freeze-dried and stored.

The supernatant was centrifuged and filtered to recover any of the finer sediment that did not settle. This was added to the sediment.

3. Analytical Methodology

A 20-ml aliquot of the filtered sample was analyzed for filtered* reactive phosphorus (FRP) by the method of Murphy and Riley (1962) as modified by John (1970). The following changes were made in

* This is equivalent to dissolved inorganic-P (DIP). However, DIP is defined as having been filtered through 0.45 μ m filter and we used 1.0 μ m. Our studies indicate no significant differences with the two methods.

Figure 2. Lake Erie Drainage Basin tributary sampling sites.

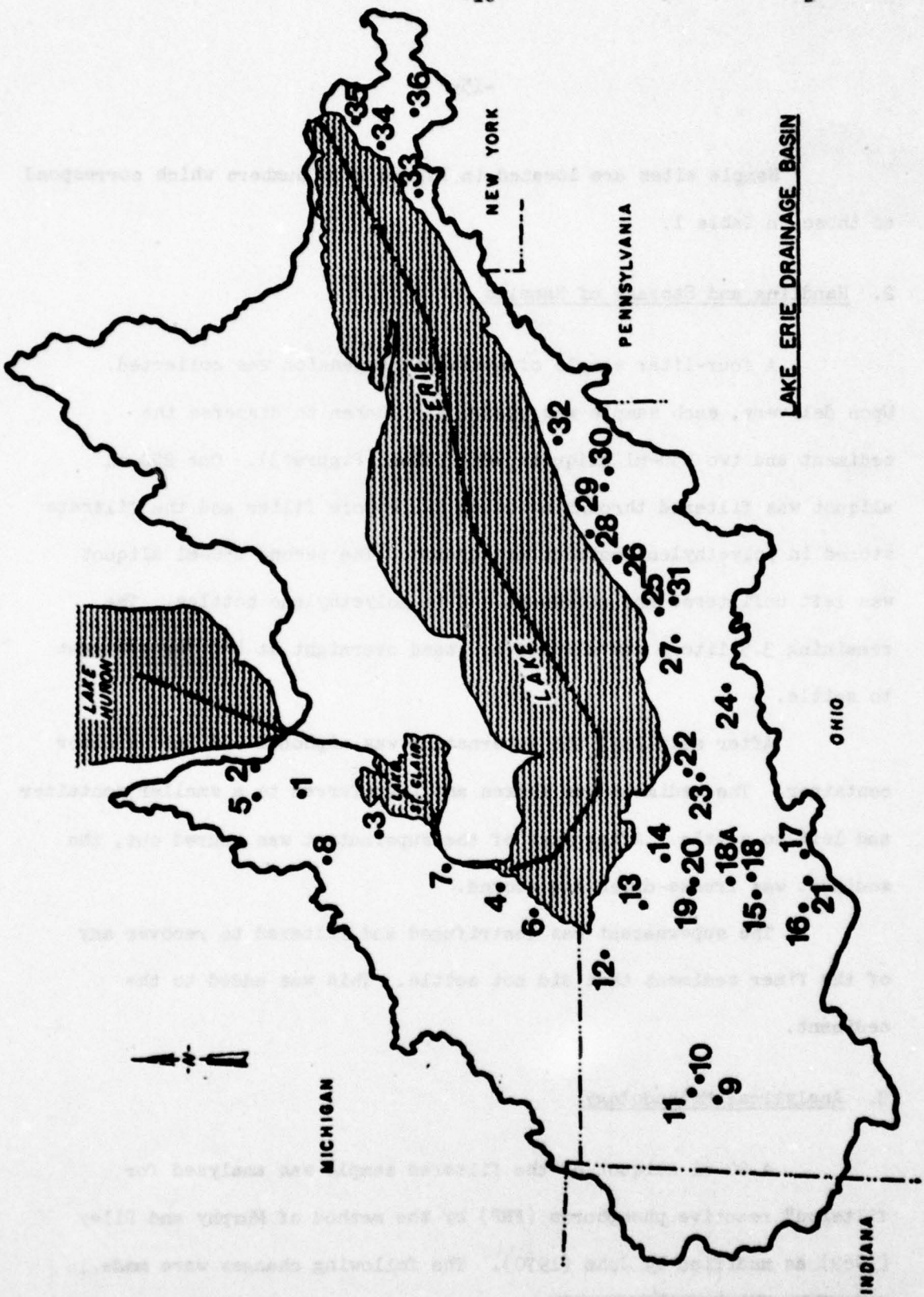


TABLE 1. CHARACTERISTICS OF LAKE ERIE THROUGH SAMPLING SITES (1977)

Map No.	Station No.	Stream	Sampling Site	County	Drainage Area mi ²	Sampling Dates	Sample No.	Mean Annual Discharge ft ³ /sec	Mean Discharge of Month Sampled ft ³ /sec	Mean Discharge of Data Sampled ft ³ /sec
Michigan										
1	04160600	Belle	Maple	St. Clair	391.09	3/5, 3/29	1, 9	89.0	172, 21	352/355 13
2	04159500	Black	Pargo	St. Clair	1243.2	3/5, 3/29	2, 10	282.0	692, 43	1120/948 41
3	04169500	Clio	St. Clair	St. Clair	1901.05	3/5, 3/29	3, 11	346.0	1384, 302	2843/3489 219
4	04160111	Harve	St. Clair	St. Clair	2351.72	3/5, 3/29	4, 12	92.0		383/266 22
5	04199900	Mill Creek	Harve	St. Clair	437.71	3/5, 3/29	5, 13	698.0	1827, 367	2780/3200 377
6	04179500	Midale	Harve	Harve	2698.18	3/5, 3/29	6, 14	12.5	72, 8.6	24721 7.1
7	04180070	Rego	West Jefferson Bridge	Wayne	1209.53	3/5, 3/29	7, 15			
8	04160800	Sandusky Creek	Drayton Plains	Oakland	34.13	3/5, 3/29	8, 16			
Ontario										
9	04160600	Anglican	Junction	Peel	6004	3/10, 4/26	25, 38	1702	2916, 2593	
10	04199500	Harve	Independence	DeWitt	9998	3/10, 7/1	26, 41			
11	04199500	Harve	DeWitt	DeWitt	1906	3/10	27			
12	04199500	Harve	Harveville	Lucas	1638.7	3/10, 4/26	28, 39	4797.0	13880, 11903	26535, 12930 4110
13	04199500	Portage	Woodville	Sandusky	1106.52	3/28, 7/5	31, 50	304.0	1185, 171	1580, 511
14	04199500	Sandusky	Frederick	Sandusky	3040.09	3/28, 7/2	34, 47	944.0	2164, 519	1760 2150/1520

TABLE 1. (Continued)

Map No.	Station No.	Stream	Sampling Site	County	Drainage Area km ²	Sampling Date	Sample No.	Mean Annual Discharge ft ³ /sec	Mean Discharge of Month Sampled ft ³ /sec	Mean Discharge of Year Sampled ft ³ /sec
Rhine-Porter-Sandusky-Huron (continued)										
15	04197000	Sandusky	Manisco	Seneca	2004.66	3/26	32	575.0	1401	1153
16	04196900	Sandusky	Upper Sandusky	Wyandot	771.62	3/28	35	241.0	167	295
17	04196000	Sandusky	Bucyrus	Crawford	229.99	3/28	30	64.6	101	142
18	04197100	Honey Creek	Milmore	Seneca	385.91	7/21	52	130	159	15
18a		Willow Creek	Tiffin	Seneca		3/21, 7/28	29, 31		321	117/305
19	04197300	Wolf Creek	Betterville	Seneca		4/5, 7/1	37, 42		44.4	
20	04197450	Wolf Creek	Betterville	Seneca	171.46	7/1	45	42	10.2	127
21	04196300	Broken Sound	Novada	Sandusky	213.42	3/28	36	100	197	1050
22	04199000	Huron	Millen	Wyandot	217.04	7/1	43	70	94	724
23	04198100	Novada Creek	Novada	Erie	960.86	7/2	46	295	716	255
						7/5	49			7123
						6/6	40	14.37		4.1

TABLE 1. (Continued)

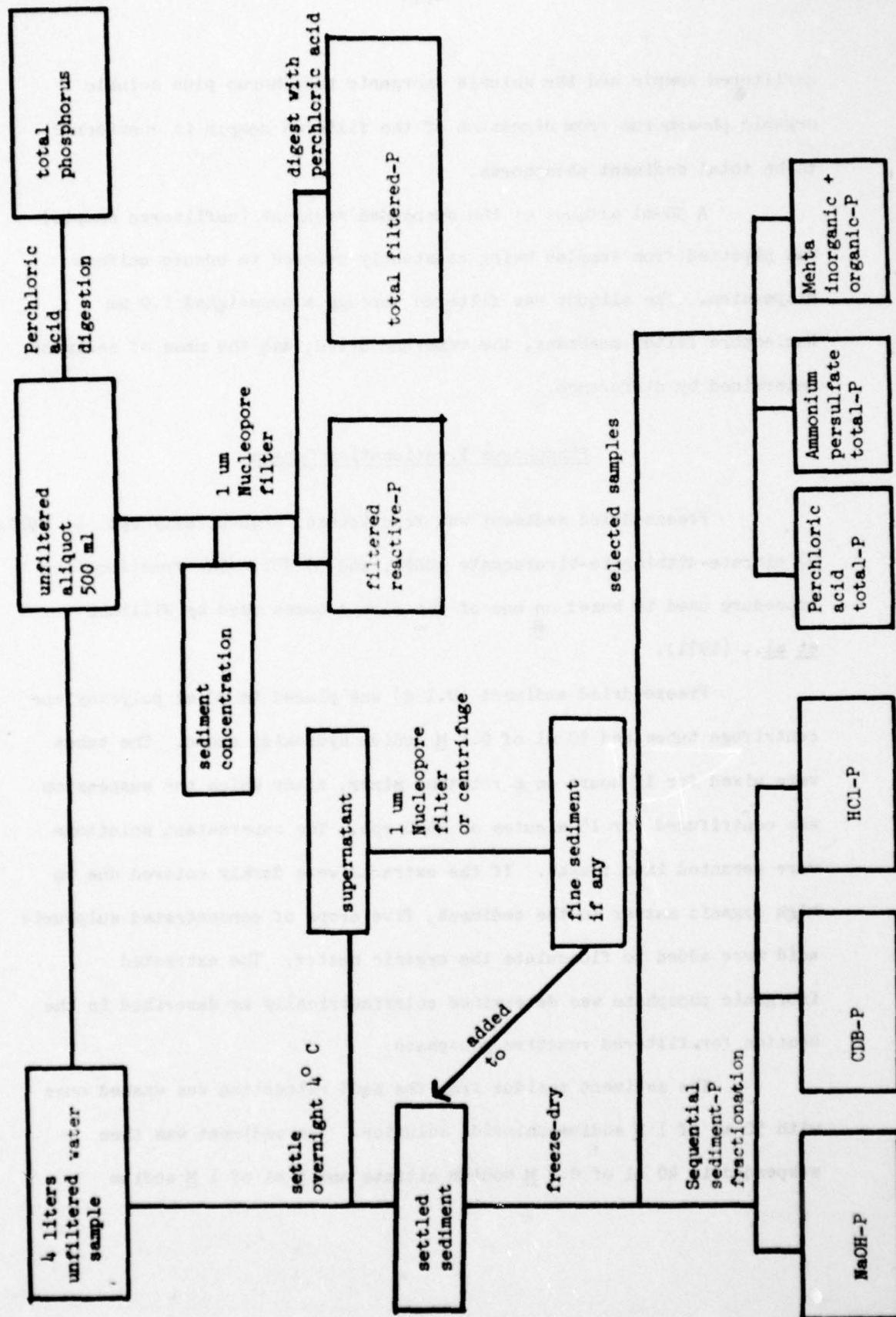
gag No. Station No.	Stream	Sampling Site	County	Drainage Area sq. mi.	Sampling Date	Sample No.	Mean Annual Discharge ft ³ /sec	Mean Discharge of Month Sampled ft ³ /sec	Mean Discharge of Data Sampled ft ³ /sec
Eastern Ohio									
24 04199800	Hoff Run	Litchfield	Madison	1.97	6/6	57			2.0
25 04200902	Big Creek	Cleveland	Cuyahoga	91.53	6/6	53	51.5	55.7	71.0
26 04209000	Chagrin	Willoughby	Lake	637.15	6/6	54	324	169	266
27 04201500	Rocky	Berea	Cuyahoga	691.53	6/6	60	260	80.9	61.0
28 04212100	Grand	Painesville	Clark	1775.15	6/6	59	934	72.5	1.0
29 04210090	Montville Mith	Montville	Columbus	0.75	6/6	58	28		1.50
30 04210100	Kimbins Creek	Hartsgrove	Ashtabula	15.04	6/6	56			7.5
31 04208000	Cuyahoga	Independence	Cuyahoga	1831.13	6/6	55	709	34.2	380
32 04212600	Hubbard Run	Ashtabula	Ashtabula	2.26	7/7	61			0.73
New York									
33 04213900	Cattaraugus Creek	Gowanda	Erie	1118.88	3/28	62		2254	2380
34 04214040	Delaware Creek	Angola	Erie	12.95-	4/23	63	731	1476	8930
35 04214200	18 Mile Creek	E. Boston	Erie	75.9	4/23	64			903
36 04214490	S. Cattaraugus Creek	Otto	Cattaraugus	66.38	4/23	65			3003
						66			1100

order to improve the stability of the blue molybdo-phosphate complex. Absorbance readings were taken with a Beckman DU Spectrophotometer at 730 nm wavelength and inorganic P concentrations determined from a standard curve.

Total phosphorus was determined by the method of Sommers and Nelson (1972). Twenty-ml aliquots of the unfiltered samples were pipetted into 50-ml digestion tubes. Five drops of concentrated sulphuric acid were added to the suspension and the samples evaporated in an oven at 105°C overnight. On cooling, 3 ml of 70% perchloric acid were added, and pyrex funnels were placed atop the tubes throughout the digestion to ensure refluxing of perchloric acid. The tubes were placed in an aluminum digestion block and the samples digested at 203°C for 75 minutes. Following digestion, the digest was allowed to cool, and then diluted with distilled water to 50 ml. The tubes were shaken to mix the contents and left to stand overnight or centrifuged to remove residues. From the clear supernatant solution 10 ml aliquots were pipetted into 50 ml tubes, neutralized with 5 N NaOH using p-nitrophenol as an indicator. The aliquot was analyzed for total phosphorus colorimetrically as described in the section for filtered reactive phosphorus.

Twenty-ml aliquots of the filtered samples were digested in 70% perchloric acid following the procedure outlined for total phosphorus digestion. The phosphorus from this digestion is the sum of soluble inorganic and soluble organic phosphorus. The difference between the values obtained from the digestion of the filtered samples and the soluble inorganic phosphorus is considered to be soluble organic phosphorus. The difference between total phosphorus obtained from digestion of the

Figure 3. Sample handling and analysis



unfiltered sample and the soluble inorganic phosphorus plus soluble organic phosphorus from digestion of the filtered sample is considered to be total sediment phosphorus.

A 50-ml aliquot of the suspended sediment (unfiltered sample) was pipetted from samples being constantly stirred to ensure uniform dispersion. The aliquot was filtered through a preweighed 1.0 μ m Nucleopore filter membrane, the membrane dried, and the mass of sediment determined by difference.

Phosphorus Fractionation Scheme

Freeze-dried sediment was fractionated sequentially by: 1) NaOH, 2) citrate-dithionite-bicarbonate (CDB), and 3) HCl. The fractionation procedure used is based on one of the five schemes used by Williams et al., (1971).

Freeze-dried sediment (0.1 g) was placed in 90-ml polyethylene centrifuge tubes and 50 ml of 0.1 M sodium hydroxide added. The tubes were mixed for 17 hours on a rotating mixer, after which the suspension was centrifuged for 15 minutes at 2400 rpm. The supernatant solutions were decanted into flasks. If the extracts were darkly colored due to high organic matter in the sediment, five drops of concentrated sulphuric acid were added to flocculate the organic matter. The extracted inorganic phosphate was determined colorimetrically as described in the section for filtered reactive phosphate.

The sediment residue from the NaOH extraction was washed once with 50 ml of 1 M sodium chloride solution. The sediment was then suspended in 40 ml of 0.3 M sodium citrate and 5 ml of 1 M sodium

bicarbonate, and then 1.0 gm of sodium dithionite was added. The suspension was heated in a water bath at 80-85°C for 15 minutes with frequent stirring. The suspension was cooled and mixed for 5 minutes on a rotating mixer, and then centrifuged for 10 minutes at 2000 rpm. The supernatant solution was decanted.

In the determination of inorganic-P after citrate-bicarbonate-dithionite extraction, there are interferences from dithionite, citrate, iron and silicon. Therefore, a simplified and more rapid procedure for the determination of reductant-soluble phosphate by a modification of Murphy and Riley (1962) ascorbic acid developed by Weaver (1974) was used. Excess sodium dithionite in the extract was oxidized by bubbling moist air through the extract over-night; 5 ml aliquots were pipetted from the air-oxidized extract into tubes, and 3 ml of 5% ammonium molybdate solution added. Addition of the 5% ammonium molybdate solution compensates for the interference from citrate. Distilled water was added to make approximately 40 ml volume and the "mixed reagent" for color development added and absorbance measured at 730 nm after 30 minutes. The blank was made by mixing 25 ml of 0.3 M sodium citrate, 1 gm of sodium dithionite, and the mixture diluted to 50 ml. This solution was oxidized in the same manner for same period of time, and 5 ml aliquot pipetted into a 50 ml tube.

The sediment residue from the CDB extraction was washed once with 1 M sodium chloride solution; 50 ml of 1 N hydrochloric acid was added and the suspension mixed in a rotating mixer for one hour. The suspension was centrifuged and the supernatant decanted; 20 ml aliquot of the extracts were pipetted into 50 ml tubes, neutralized with

5 N sodium hydroxide and the phosphate determined colorimetrically as for filtered reactive phosphorus. The residue after HCl extraction was digested with perchloric acid as before and is termed residual inorganic-P.

Total Phosphorus in Sediment

Total phosphorus on sediment was determined by the following three methods:

1. Perchloric acid
2. Persulphate
3. Mehta

Perchloric acid method: Total phosphorus of the sediment was determined by the method of Sommers and Nelson (1972). A 0.1-gm sample of the freeze-dried sediment was placed in a digestion tube and digested in 3 ml of perchloric acid at 203° for 75 minutes. Following digestion, the digest was allowed to cool and diluted with distilled water to 50 ml. The tubes were shaken and left to stand overnight or centrifuged to remove residues. From the clear supernatant solution, 3-ml aliquots were pipetted into 50 ml tubes, neutralized with 5 N NaOH using p-nitrophenol as an indicator. The aliquot was analyzed for total phosphorus colorimetrically as described in the section for FRP.

Mehta method: Total phosphorus in sediment was determined by the method of Mehta (1954). The method was modified slightly in the quantity of extracting reagents in proportion to the amount of sediment analyzed. A 0.1 gm sample of freeze-dried sediment was placed in digestion tube, and 5 ml of concentrated hydrochloric acid added, and then heated for 10 minutes at 70°C. An additional 5 ml of concentrated hydrochloric

acid was added, mixed and allowed to stand for one hour. Ten milliliters of distilled water was added, mixed, and then centrifuged. The clear supernatant solution was poured into a 50-ml tube, 10 ml of 0.5 N sodium hydroxide was added to the residue, stirred and the suspension allowed to stand at room temperature for one hour, after which it was centrifuged. The supernatant solution was poured into the tube containing the concentrated hydrochloric acid extract. Twenty milliliters of 0.5 N sodium hydroxide was added to the residue, stirred and covered with an inverted 50 ml beaker, and warmed in the oven at 90°C for 8 hours. The tube was cooled, centrifuged and the supernatant poured into the tube of HCl and NaOH extracts. The volume was made to 50 ml and mixed. Two 10-ml aliquots of the mixed extract were placed in two separate tubes. The first aliquot was analyzed for total inorganic phosphorus colorimetrically as described for FRP. The second aliquot was digested with perchloric acid as described previously, then analyzed for inorganic-P. The difference between the digested and nondigested aliquots is organic-P.

Persulphate method: Total phosphorus in sediments was determined by the persulphate method described in the Standard Methods for the Examination of Water and Wastewater (1975). The procedure was modified for the analysis of 0.05 gm of sediment suspended in water. A 0.05-gm sample of sediment was placed in a 100-ml volumetric flask and about 60 ml of distilled water added; 1 ml of sulphuric acid solution and 15 ml of potassium persulphate solution were added and the mixture heated for 30 minutes in an autoclave or pressure cooker at 15-20 psi. The mixture was then cooled, made to 100 ml, and an aliquot taken, neutralized with NaOH and phosphorus determined by the procedure described previously for FRP.

RESULTS AND DISCUSSION

The data was organized into the four geographical areas discussed previously. The complete data set is given in Appendix A for all parameters measured. Summary statistics by area are given in Table 2, and mean and S.D. are presented graphically in Figure 4. Sediment concentrations were significantly higher in the New York samples, with the western Ohio samples intermediate. Filtered reactive-P was highest in the eastern Ohio streams although the variation was quite high. Total P reflected both the high sediment concentrations in New York streams and high FRP in the eastern Ohio streams. Total sediment-P is calculated as the difference between total and total filtered-P divided by sediment concentration. Our data show that these values are overestimated at low sediment concentrations (Appendix A) when compared with direct measurement of total P on sediment. Errors in the three parameters which are used to calculate total sediment-P may contribute to this difference.

The NaOH-P was essentially the same for Michigan and Ohio streams and these were significantly higher than the New York samples. CDB-P showed the same trend; the eastern Ohio streams had significantly higher values than western Ohio and New York was again lower than the other three areas. On the other hand, HCl-P (apatite) was highest in the New York streams; apatite-P was lowest of three fractions in the Ohio and Michigan streams and highest in the New York tributaries. Sum of the two fractions that are considered to be available (NaOH + CDB) was highest in the eastern Ohio samples, significantly higher than western Ohio and New York. New York was lower than the other three areas.

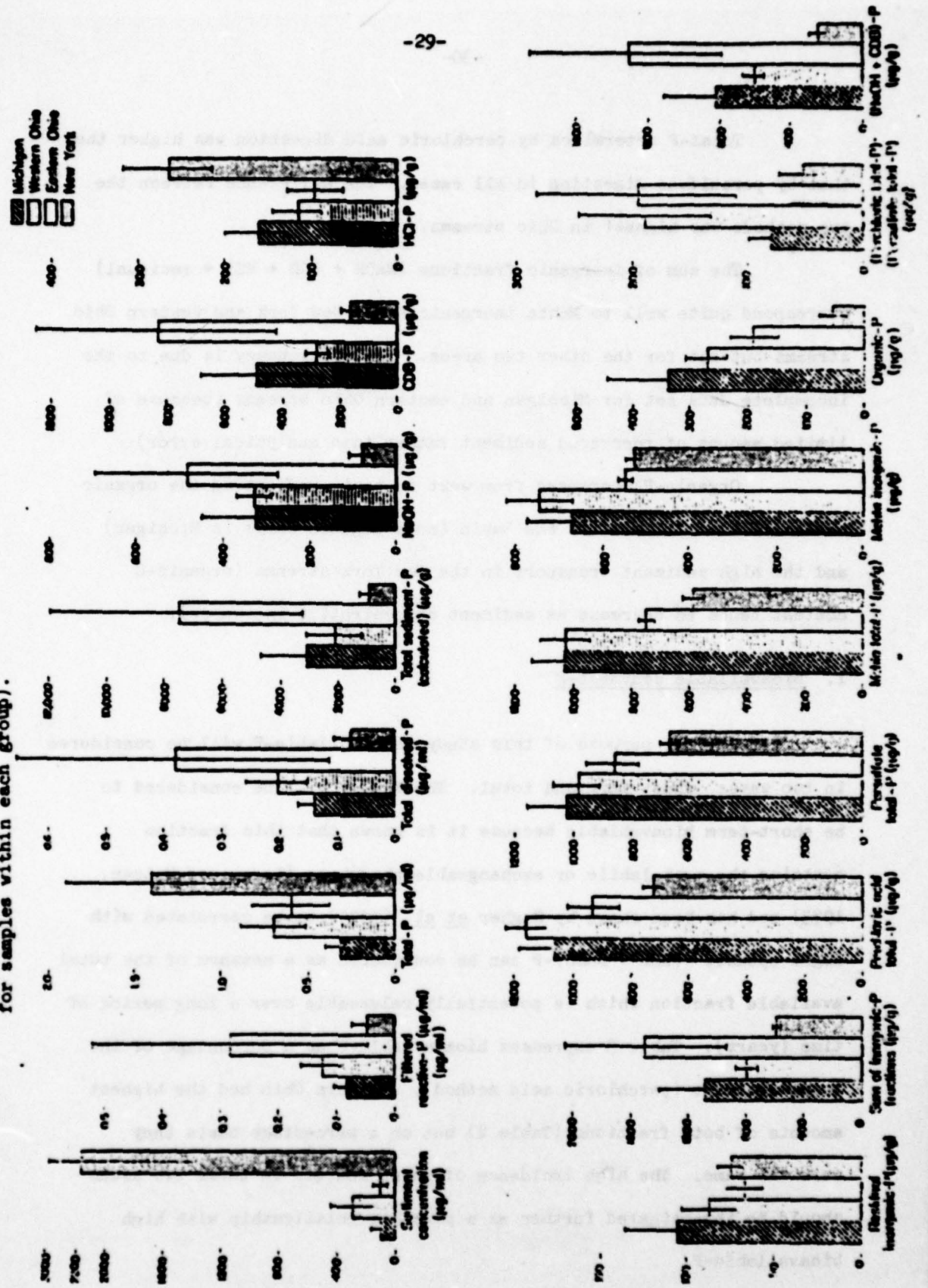
TABLE 2. SUMMARY OF SEDIMENT-P CHARACTERISTICS

Parameter	No. of Observations	Mean	S.D.	Std. Error of Mean	Minimum	Maximum
Michigan						
Sediment concentration	24	97.5	87.8	17.9	4.0	334.0
Filtered reactive-P	24	0.086	0.043	0.009	0.016	0.151
Total-P	24	0.317	0.170	0.035	0.063	0.606
Total filtered-P	24	0.141	0.054	0.011	0.031	0.278
Total sediment-P	24	3095.0	3168.1	646.7	160.2	15666.7
NaOH-P	24	328.9	238.3	48.7	34.3	1069.4
CDB-P	21	493.7	380.3	83.0	106.2	1614.3
HCl-P	24	162.9	72.2	14.7	40.8	340.6
Residual inorganic-P	21	106.1	58.2	12.7	29.2	245.0
Sum inorganic-P fractions	21	1096.6	603.7	131.7	525.1	2779.7
Perchloric acid total-P	9	1065.5	233.6	77.9	735.0	1477.0
Persulfate total-P	12	1023.5	265.8	76.7	673.2	1524.6
Mehta total-P	11	1032.7	266.2	68.2	668.2	1348.9
Mehta inorganic-P	11	675.0	201.8	60.9	440.6	1118.7
Organic-P	8	341.1	203.3	71.9	96.5	778.4
(Per-Pers) total-P	9	80.1	37.6	12.5	32.4	126.8
(NaOH+CDB)-P	21	825.3	571.0	124.6	332.2	2408.2
Maumee-Portage-Sandusky-Huron						
Sediment concentration	28	348.8	340.0	64.2	48.0	1204.0
Filtered reactive-P	28	0.123	0.074	0.014	0.025	0.374
Total-P	28	0.706	0.365	0.069	0.234	1.452
Total filtered-P	28	0.201	0.107	0.020	0.082	0.505
Total sediment-P	28	2240.5	2447.0	462.4	901.8	13354.2
NaOH-P	28	330.1	79.2	15.0	121.3	480.8
CDB-P	23	282.4	77.9	16.2	159.3	432.8
HCl-P	28	113.2	64.3	12.1	19.6	261.5
Residual inorganic-P	23	86.1	31.0	6.5	39.2	137.2
Sum inorganic-P fractions	23	787.0	153.6	32.0	503.9	1003.4
Perchloric acid total-P	22	1168.4	136.1	29.0	909.0	1380.4
Persulfate total-P	28	978.4	169.4	32.0	663.3	1287.0
Mehta total-P	26	1029.0	170.8	33.5	705.4	1441.3
Mehta inorganic-P	25	751.8	152.5	30.5	475.2	1211.3
Organic-P	23	270.1	72.7	15.2	173.2	475.2
(Per-Pers) total-P	21	190.2	115.8	25.3	37.8	430.9
(NaOH+CDB)-P	23	598.9	112.2	23.4	394.9	762.7

Parameter	No. of Observations	Mean	S.D.	Std. Error of Mean	Minimum	Maximum
Eastern Ohio						
Sediment concentration	9	93.6	119.6	39.9	12.0	384.0
Filtered reactive-P	9	0.286	0.492	0.164	0.013	1.485
Total-P	9	0.604	0.518	0.172	0.076	1.749
Total filtered-P	9	0.379	0.555	0.185	0.030	1.768
Total sediment-P	9	7593.0	8613.7	2871.2	1049.5	28555.6
NaOH-P	8	491.5	422.3	149.3	88.6	1332.4
CDB-P	8	834.9	859.3	303.8	181.8	2160.1
HCl-P	8	101.4	61.4	21.7	16.5	180.7
Residual inorganic-P	8	68.5	21.2	7.5	39.2	107.8
Sum inorganic-P fractions	8	1426.2	1134.0	400.9	542.2	3085.6
Perchloric acid total-P	2	934.2	178.5	126.2	808.0	1060.5
Persulfate total-P	3	867.1	224.4	129.5	732.6	1126.1
Mehta total-P	2	742.5	52.5	37.1	705.4	779.6
Mehta inorganic-P	2	551.9	31.5	22.3	529.6	574.2
Organic-P	2	190.6	84.0	59.4	131.2	250.0
(Per-Pers)* total-P	2	196.7	171.5	121.3	75.4	318.0
(NaOH+CDB)-P	8	1326.4	1090.4	385.5	393.8	2798.3
New York						
Sediment concentration	5	2163.2	1631.1	729.4	292.0	3666.0
Filtered reactive-P	5	0.048	0.051	0.023	0.016	0.135
Total-P	5	1.402	0.985	0.441	0.479	2.951
Total filtered-P	5	0.077	0.053	0.024	0.044	0.170
Total sediment-P	5	973.8	673.2	301.0	309.9	2054.8
NaOH-P	5	83.2	56.4	25.2	36.1	180.1
CDB-P	5	169.9	60.3	27.0	93.9	249.1
HCl-P	5	265.8	99.1	44.3	115.2	357.7
Residual inorganic-P	5	76.4	13.7	6.1	58.8	91.9
Sum inorganic-P fractions	5	595.4	49.2	22.0	546.6	661.3
Perchloric acid total-P	5	720.5	71.0	31.8	664.9	841.6
Persulfate total-P	5	669.2	60.5	27.0	613.8	772.2
Mehta total-P	5	587.2	71.1	31.8	519.8	668.2
Mehta inorganic-P	5	532.6	33.1	14.8	495.0	574.2
Organic-P	5	54.6	41.8	18.7	14.9	104.6
(Per-Pers)* total-P	5	51.2	41.2	18.4	1.6	110.0
(NaOH+CDB)-P	5	253.1	103.2	46.2	165.0	429.2

* Perchloric total-P minus persulfate total-P.

Figure 4. Summary of suspended sediment parameters (mean and standard deviation for samples within each group).



Total-P determined by perchloric acid digestion was higher than that by persulfate digestion in all cases. The difference between the two methods was highest in Ohio streams.

The sum of inorganic fractions (NaOH + CDB + HCl + residual) correspond quite well to Mehta inorganic-P for New York and western Ohio streams but not for the other two areas. The discrepancy is due to the incomplete data set for Michigan and eastern Ohio streams (because of limited amount of recovered sediment rather than analytical error).

Organic-P decreased from west to east, reflecting the organic matter content of soils in the Basin (more organic soils in Michigan) and the high sediment transport in the New York streams (organic-C content tends to decrease as sediment concentration increases).

1. Bioavailable sediment-P

For the purpose of this study, bioavailable-P will be considered in two ways: short-term and total. The NaOH-P will be considered to be short-term bioavailable because it is known that this fraction contains the most labile or exchangeable phosphate (Logan and McLean, 1973) and has been shown by Sagher *et al.* (1975) to be correlated with algal uptake. (CDB + NaOH)-P can be considered as a measure of the total available fraction which is potentially releasable over a long period of time (years). Table 3 expresses bioavailable-P as a percentage of the total sediment (perchloric acid method). Eastern Ohio had the highest amounts of both fractions (Table 2) but on a percentage basis they were the same. The high incidence of point sources in these two areas should be investigated further as a possible relationship with high bioavailable-P.

TABLE 3. PERCENT BIOAVAILABILITY OF SEDIMENT-P*

	NaOH-P	CDB-P	(NaOH + CDB)-P
Michigan	30.0	45.0	75.0
Western Ohio	41.9	35.9	77.8
Eastern Ohio	32.8	55.8	88.6
New York	14.0	28.5	42.5

* Expressed as percent of total sediment inorganic phosphorus.

New York samples were lowest in both NaOH-P and CDB-P and would be expected to support much less algal growth than the streams to the west. On a percentage basis, NaOH-P was lower than other areas. Studies in Fall Creek, New York (Porter, 1975) used a desorption technique to measure readily available phosphorus and concluded that about 4% of the total sediment-P was available by this technique.

Actual bioavailability of sediment-P is strongly dependent on equilibrium kinetics: the rate at which sorbed P is released when a demand or sink (algal uptake) is in operation, and the period during which the sediment is positionally accessible to the algae. In deep lakes with significant stratification, as in the eastern, and to a lesser extent, the central Lake Erie basins, sediment may be in contact with algae for short periods only, during which time NaOH-P will be most important. During anoxia and subsequent lake inversion, P released from the CDB fraction will become significant. Therefore, chemical fractionation data must be interpreted in light of dynamics of the receiving lake.

Simple moment correlations were run between all parameters and Table 4 gives those correlations which were significant at the 5% level of probability or better.^{1/} Sediment concentration was positively correlated with total-P ($\mu\text{g/ml}$) and HCl-P, and negatively correlated with NaOH-P, total sediment-P and organic-P. A closer examination of the data set (Appendix A) indicates that many of these relationships are reflecting the influence of the New York samples, a number of which were the highest in suspended solids found in the study. The results are, however, supported by the work of Porter (1975), Logan (1978) and Armstrong *et al.* (1977) who found that, at lower sediment concentrations the sediment that is transported contains more clay and organic matter and is higher in sediment-P. Armstrong *et al.* (1977) used a chemical fractionation scheme to characterize suspended sediments from Great Lakes tributaries. They fractionated the sediment into various particle size fractions and showed that available sediment-P was higher on the finer textured material.

Both NaOH-P and CDB-P were correlated with total sediment-P as expected. Step-wise linear regression correlations were run on the various fractions and these are given in Table 5. None of the equations had very high R^2 values. However, a few trends were apparent. CDB-P and (CDB+NaOH)-P were negatively related to sediment concentration, while HCl-P was positively correlated. Total filtered-P was positively correlated with each fraction except CDB-P, and NaOH-P was positively correlated with organic-P. The relationship of this fraction with organic-P is not unexpected since NaOH is known to extract organic

^{1/} Complete correlation matrix is given in Appendix B.

Table 4. Simple moment correlation coefficients between sediment-P parameters 1/

SEDUCE	FWP	TOTP	TPP	HAOSP	CSOP	HCIP	RESIP	FRALP 1/2	FRCTP 1/2	FRSTP	MEATP 1/2	CHOSP	DISPP	SCM
SEDUCE														
FWP		0.74°	0.31	0.94°	-0.30	0.37°			-0.49°	-0.40°	-0.33°	-0.31°	-0.38°	-0.31
TOTP	0.74°		0.37°				-0.26		0.39	-0.30	-0.42°			0.17°
TPP	0.31	0.37°		0.99°				0.40°	0.46°			0.46°	0.39	0.44
HAOSP	-0.30		0.94°		0.96°	0.34°		0.42°	0.86°	0.64°	0.73°	0.38	0.60°	0.79°
CSOP	0.94°	0.37°	0.99°				0.27	0.94°	0.40	0.61°	0.49°	0.60°		0.94°
HCIP	0.37°		0.94°	0.96°	0.34°				-0.44°			-0.40	-0.45°	
RESIP		-0.26				0.27		0.42°	0.42	0.31°				0.36°
FRALP	0.45°		0.40°	0.77°	0.94°		0.42°		0.67°	0.83°	0.70°	0.68°		0.99°
FRCTP	-0.49°	0.39	0.46°	0.86°	0.40	-0.43°	0.42	0.67°		0.87°	0.81°	0.56°	0.45°	0.83°
FRSTP	-0.40°	-0.30		0.64°	0.61°		0.51°	0.83°	0.86°		0.83°	0.46°		0.82°
MEATP	-0.55°	-0.42°		0.75°	0.49°			0.70°	0.81°	0.83°		0.65°		0.79°
CHOSP	-0.31		0.39	0.38	0.61°		0.47°	0.68°	0.43°	0.58°	0.64°			0.70°
DISPP	-0.52°	0.32	-0.37	0.46°	0.60°	-0.40			0.56°	0.46°	0.65°			0.48°
SCM	-0.31	0.47	0.44°	0.79°	0.94°		0.36°	0.99°	0.83°	0.82°	0.79°	0.70°	0.48°	

1/ All coefficients given are significant at the 5% level or better. Those with "°" are significant at the 1% level.

2/ Diff P = Perchloric acid P (FRCTP) - Perchloric P (FRSTP)

3/ Sum = Residual P - CSOP - FWP / RESIP - Residual Inorg.-P; FRALP - Sum of Inorg. fractions; MEATP - Mehta total-P; MEATP - Mehta Inorg.-P

material; although only the inorganic-P in the NaOH extract was measured, it is possible that the NaOH may be extracting a part of the inorganic-P that is bound to organic matter or there may be extraction of polyphosphates with subsequent hydrolysis to inorganic reactive-P.

TABLE 5. STEPWISE LINEAR REGRESSION EQUATIONS

$$\text{NaOH-P} = 333.1 \text{ total filtered-P} + 0.26 \text{ organic-P} - 0.60 \text{ HCl-P} + 217.3 \quad R^2 = 0.57$$

$$\text{CDB-P} = 1.52 \text{ residual inorganic-P} - 0.04 \text{ sediment conc.} + 169.2 \quad R^2 = 0.39$$

$$\begin{aligned} \text{HCl-P} = & 0.03 \text{ sediment concentration} + 162.9 \text{ filtered} \\ & \text{reactive-P} + 205.8 \text{ total filtered-P} - 0.30 \\ & \text{NaOH-P} - 0.23 \text{ (Perchloric acid total-P-} \\ & \text{persulfate acid total-P)} + 182.2 \quad R^2 = 0.56 \end{aligned}$$

$$\begin{aligned} (\text{NaOH+CDB})\text{-P} = & 600.7 \text{ total filtered-P} + 2.03 \text{ residual} \\ & \text{inorganic-P} - 0.06 \text{ sediment concentra-} \\ & \text{tion} - 0.57 \text{ HCl-P} + 373.4 \quad R^2 = 0.63 \end{aligned}$$

2. Total Sediment-P Analysis

One of the objectives of this study was to compare the persulfate method of total-P analysis with perchloric acid digestion used in soil analysis. O'Connor and Syers (1975) showed that when water samples contain significant amounts of mineral sediment, persulfate digestion fails to recover all of the P present. They attributed the difference between persulfate and the more rigorous perchloric acid digestion to highly resistant inorganic-P forms.

Our data (Table 2) showed that perchloric acid does extract more P than persulfate in all cases. The difference in sediment-P extracted was positively correlated with total filtered-P and negatively correlated with HCl-P. Step-wise linear regression gave the following equation:

$$\begin{aligned} \text{Difference in total-P} &= 517.9 \text{ total filtered-P} - 0.38 \text{ CDB-P} - 0.67 \text{ HCl-P} \\ &+ 258.2 \qquad \qquad \qquad R^2 = 0.42 \end{aligned}$$

The R^2 was quite low but confirmed the negative correlation with HCl-P. Evidently the perchloric acid is extracting some form of P in the samples from Ohio and Michigan not seen in the New York samples and that this form is not organic-P or residual inorganic-P since these did not correlate.

3. Extrapolation to Lake Erie

Monitored tributary loads of sediment to Lake Erie in recent years have shown that most of the sediment is transported during storm events. These sediments are primarily of surficial soil origin, with detrital sediment and street litter from urban runoff of lesser significance. PLUARG - Task C studies in the Menomonee River Basin and work by Cowen and Lee (1976) in New York and Wisconsin indicate that urban sediments have phosphorus characteristics similar to those from agricultural areas.

Sediment-P bioavailability as measured by chemical extraction, bioassay or other techniques reflects, for the most part, native soil phosphorus levels in Basin soils and its chemical and biological reactivity, fertilizer phosphorus additions, the degree to which sediment is enriched in P because of preferential clay transport, and the adsorption of point source soluble inorganic P by stream sediments.

Based on these considerations, sediments from the more urbanized tributary areas in Michigan and eastern Ohio and those from the high clay agricultural basins in western Ohio should have the highest BSP per unit sediment load. The high total annual sediment load in the Maumee, Portage and Sandusky basins together with high BSP point to these areas as the major contributors of BSP. In addition, the discharge of these sediments into the shallow western basin of Lake Erie make their impact on algal production even more significant. As one proceeds into the central and eastern basins, the significant contribution of sediment-P to algal growth is diminished for two reasons: lower sediment loads and BSP, and shorter contact time between algae and sediment.

Reductions in total sediment load to the Lake in concert with point source phosphorus reductions have been proposed. Sediment load reductions in the NW Ohio region of the Lake basin should receive greatest attention. In this regard, two points should be made: 1) While total fertilizer P additions since modern chemical fertilization began about 40 years ago have only increased soil-P levels by about 10%, these additions have a higher BSP than native soil-P. Logan (1978) found that Lake Erie Basin agricultural soils had available-P levels sufficient for optimum crop production and state extension programs should strive to maintain these levels rather than increase them further. 2) sediment-P reductions will not be as great as sediment reduction when conservation programs are implemented, because these programs are more efficient at preventing the loss of coarse-grained sediment than the fine sediment with its higher P content. The results of Armstrong *et al.* (1977) indicate that BSP will also diminish slower than sediment reduction.

CONCLUSIONS

1. Bioavailable sediment-P as estimated by NaOH extraction was on the order of 30-40% of total inorganic sediment-P for suspended sediments in Michigan and Ohio. New York sediments were only half as much, about 14%.
2. New York sediments had the highest content of apatite-P and were lowest in total-P.
3. Persulfate gave lower total sediment-P values than perchloric acid in all cases; this difference was negatively correlated with apatite-P but was not correlated with organic-P or residual inorganic-P.

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APPENDIX

APPENDIX A

14335 WEDNESDAY, AUGUST 23, 1979 22

SUMMARY OF DATA OF INDIVIDUAL SITES

QOS	DATE	SITE	SECCN	SP	TSP	IFP	TSOP	WADMP	CHMP	MCLP
1	MAR 5	BELLE	142	0.123	0.349	0.196	2521.4	431.5	269.5	79.6
2	MAR 5	BLACK	176	0.113	0.494	0.177	1755.7	237.0	141.9	131.7
3	MAR 5	CLIVTON	214	0.114	0.454	0.209	1412.2	267.1	216.4	197.9
4	MAR 5	MURON	16	0.144	0.164	0.132	750.0	34.3	.	159.3
5	MAR 5	MILL CREEK	48	0.141	0.385	0.146	2774.4	190.1	302.2	63.1
6	MAR 5	RAISIN	234	0.114	0.606	0.177	1533.3	599.0	.	200.3
7	MAR 5	ROUGE	142	0.111	0.530	0.278	1401.2	317.3	351.2	243.8
8	MAR 5	SASABAW	156	0.115	0.113	0.128	160.2	396.4	.	103.0
9	MAR 29	BELLE	58	0.134	0.240	0.107	2275.9	466.7	243.2	163.5
10	MAR 29	BLACK	146	0.136	0.404	0.132	1863.0	241.3	204.2	121.3
11	MAR 29	CLIVTON	133	0.104	0.340	0.114	1637.7	103.5	225.7	159.6
12	MAR 29	MURON	26	0.142	0.177	0.092	3415.4	154.4	313.5	340.6
13	MAR 29	MILL CREEK	46	0.075	0.252	0.152	2739.1	320.1	606.5	129.5
14	MAR 29	RAISIN	334	0.094	0.549	0.193	1095.8	96.4	424.7	145.2
15	MAR 29	ROUGE	128	0.133	0.291	0.215	1976.6	41.7	402.2	172.7
16	MAR 29	SASABAW	12	0.135	0.107	0.089	1583.3	210.8	585.2	62.5
17	MAR 16	BELLE	6	0.163	0.196	0.101	15666.7	1049.4	1336.8	130.5
18	MAR 16	BLACK	10	0.132	0.145	0.113	3200.0	660.9	1614.3	188.0
19	MAR 16	CLIVTON	52	0.175	0.372	0.132	4615.4	209.5	337.6	254.2
20	MAR 16	MURON	10	0.124	0.124	0.107	1400.0	400.0	789.8	274.4
21	MAR 16	MILL CREEK	4	0.104	0.150	0.125	6000.0	653.3	791.9	40.9
22	MAR 16	RAISIN	112	0.102	0.303	0.103	1973.2	128.0	429.6	168.4
23	MAR 16	ROUGE	80	0.131	0.404	0.138	3325.0	243.8	616.6	243.8
24	MAR 16	SASABAW	4	0.116	0.063	0.031	4000.0	541.0	106.2	132.7
25	MAR 10	AUGLAISE	51	0.133	0.234	0.164	1346.2	121.3	273.6	94.3

QOS	RESIP	PRATP	PRCTP	PRSTP	WATP	WATP	ORGP	DIFFP	LOC	SUM	PERNA	PERTA
1	83.3	863.9	1212.0	1173.1	1293.2	514.9	778.4	33.9	1	701.0	0.256023	0.578383
2	53.9	614.5	1005.8	920.7	1076.6	702.4	373.7	25.1	1	428.9	0.235633	0.428427
3	53.9	767.1	1077.2	950.4	1107.6	772.2	335.4	126.9	1	483.5	0.247958	0.448849
4	137.2	682.6	.	801.9	773.4	732.6	.	.	1	482.3	.	.
5	.	1477.0	1477.0	1356.3	1249.4	440.6	.	120.7	1	668.5	0.344417	.
6	63.6	980.9	1281.8	1168.2	1051.4	470.2	.	119.6	1	668.5	0.246359	0.519102
7	.	.	.	.	.	.	.	.	1	.	.	.
8	73.5	956.9	.	.	.	.	.	.	1	719.9	.	.
9	58.1	625.6	993.2	900.9	1070.4	693.0	377.4	92.3	1	445.5	0.242952	0.448550
10	34.3	525.1	735.0	673.2	669.2	544.5	349.0	61.8	1	332.2	0.140816	0.451973
11	29.2	842.7	.	.	.	.	.	.	1	472.9	.	.
12	149.4	1205.5	.	.	.	.	.	.	1	926.6	.	.
13	83.3	740.1	791.2	742.5	742.5	554.4	191.1	48.7	1	511.1	0.109201	0.445981
14	93.1	707.7	.	.	.	.	.	.	1	441.9	.	.
15	131.0	993.1	.	.	.	.	.	.	1	799.6	.	.
16	241.0	2779.7	.	.	.	.	.	.	1	2408.2	.	.
17	159.5	2622.7	.	.	.	.	.	.	1	2275.2	.	.
18	117.6	918.9	.	1243.2	.	.	.	.	1	547.1	.	.
19	139.1	1599.3	.	.	.	.	.	.	1	1195.8	.	.
20	94.1	1575.1	.	.	.	.	.	.	1	1445.2	.	.
21	86.2	205.2	1010.0	821.7	977.5	991.1	96.5	32.4	1	543.6	0.126733	0.543168
22	93.0	1197.2	.	1524.6	1347.5	1118.7	230.2	.	1	860.4	.	.
23	245.0	1024.4	1	687.2	.	.
24	68.9	538.2	929.2	702.9	804.4	554.4	250.0	225.3	2	394.9	0.130542	0.424989

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APPENDIX A Continued

SUMMARY OF DATA OF INDIVIDUAL SITES

14:35 WEDNESDAY, AUGUST 23, 1978 23

OBS	DATE	SITE	SECON	FRP	10TP	TFF	TSEDP	MAOMP	CDMP	MCLP		
26	MAR 10	MAUREE/INDEPENDENCE	112	0.129	0.360	0.177	1675.9	354.0	-	130.5		
27	MAR 10	TIPPIN	75	0.153	0.410	0.190	3142.8	314.8	-	168.4		
28	MAR 10	MAUREE/WATERVILLE	143	0.172	0.511	0.170	2233.3	426.3	-	145.5		
29	MAR 21	MONEY CREEK	120	0.143	0.366	0.164	1463.8	434.9	285.5	69.0		
30	MAR 28	SANDUSKY/BUCKRUS	224	0.147	0.940	0.259	3044.6	261.5	249.1	261.5		
31	MAR 28	MONEY CREEK	160	0.142	0.426	0.214	1700.0	423.9	-	82.5		
32	MAR 28	SANDUSKY/MEXICO	340	0.145	0.445	0.209	1667.6	359.5	359.2	203.4		
33	MAR 23	PORTAGE	160	0.056	0.435	0.151	1412.5	442.2	-	254.2		
34	MAR 28	SANDUSKY/FREEMONT	376	0.065	0.815	0.447	1244.7	490.8	228.7	144.6		
35	MAR 23	SANDUSKY/U-SANDUSKY	288	0.157	0.625	0.227	1391.8	317.3	269.5	115.2		
36	MAR 28	MCLF EAST	193	0.128	0.422	0.189	1181.8	293.6	224.6	120.7		
37	APR 5	MONEY CREEK	114	0.054	0.372	0.144	2000.0	338.3	367.5	53.3		
38	APR 25	AUGLAISE	122	0.133	0.395	0.239	1196.7	329.9	298.1	140.3		
39	APR 26	MAUREE/WATERVILLE	248	0.133	0.619	0.195	1705.6	309.9	412.4	192.9		
40	JUNE 4	NORMALK	49	0.054	0.723	0.092	13354.2	266.2	159.3	19.6		
41	JULY 1	MAUREE/INDEPENDENCE	164	0.113	0.341	0.126	1189.0	217.9	294.0	133.5		
42	JULY 1	MONEY CREEK	1184	0.034	1.358	0.107	1056.6	354.1	204.2	23.3		
43	JULY 1	BUCKRUS CREEK	1204	0.059	1.452	0.126	1101.3	332.3	177.5	31.2		
44	JULY 1	WILLOW CREEK	959	0.079	1.119	0.215	443.6	329.2	179.5	29.2		
45	JULY 1	WOLF WEST	370	0.103	0.606	0.146	1243.2	311.5	196.0	116.4		
46	JULY 2	BACKEN CREEK	194	0.074	1.376	0.113	6670.1	259.2	220.5	55.1		
47	JULY 2	SANDUSKY/FREEMONT	278	0.079	0.625	0.095	1193.2	395.2	367.5	113.3		
48	JULY 3	SANDUSKY/FREEMONT	730	0.066	0.979	0.108	1906.5	290.6	310.3	68.6		
49	JULY 5	MURON	1008	0.025	1.300	0.391	901.8	267.8	381.5	76.0		
50	JULY 5	PORTAGE	318	0.374	0.562	0.379	2521.4	276.4	294.0	139.6		
OBS	RESIP	FRAP	PRCTP	PRSTP	MNATP	MNAIP	DRGP	DTFFP	LOC	SUM	PERNA	PERTA
26	.	.	1153.1	1009.8	1002.4	479.2	.	143.3	2	.	0.306999	.
27	.	.	.	950.4	1157.1	643.5	.	.	2	.	.	.
28	.	.	1251.3	1168.2	1132.3	787.1	345.2	93.1	2	.	0.340686	.
29	44.1	932.5	1161.5	940.5	1002.4	762.3	240.1	221.0	2	720.4	0.374430	0.620232
30	39.2	811.3	942.5	702.9	953.9	544.5	309.4	239.6	2	510.6	0.277454	0.561751
31	.	.	.	663.3	.	.	.	.	2	.	.	.
32	78.4	1080.5	1136.2	1029.6	940.0	811.8	178.2	106.6	2	718.7	0.316406	0.632547
33	75.4	932.5	1390.4	1267.2	1441.3	1211.3	230.0	360.7	2	709.5	0.348305	0.513921
34	73.5	775.5	.	900.9	1101.4	772.2	329.2	367.5	2	586.8	.	.
35	75.5	702.4	909.0	971.2	940.5	702.9	329.6	37.9	2	508.2	0.311991	0.559076
36	132.3	941.4	.	1194.0	1237.5	910.3	326.7	.	2	755.8	.	.
37	25.2	855.5	1144.6	1034.5	977.5	742.5	235.1	175.1	2	627.0	0.287349	0.547790
38	94.9	1000.1	1270.9	1197.9	1157.1	877.8	279.3	73.0	2	722.3	0.243843	0.568337
39	58.3	503.9	.	836.0	.	.	.	.	2	425.5	.	.
40	137.2	782.6	1321.4	960.3	940.5	722.7	217.8	361.1	2	511.9	0.184901	0.337392
41	63.7	645.3	1228.8	861.3	977.6	693.0	294.0	367.5	2	559.3	0.288167	0.454346
42	68.6	604.6	1035.2	910.8	973.4	722.7	180.7	124.4	2	509.8	0.321001	0.492465
43	44	590.8	1262.5	831.6	953.9	673.2	180.7	437.9	2	508.7	0.260752	0.402931
44	53.9	721.9	1270.9	1149.4	1039.5	693.0	346.5	122.5	2	507.5	0.245102	0.399323
45	99.0	603.4	1060.5	961.3	903.4	693.0	210.4	199.2	2	479.7	0.244413	0.432334
46	63.6	1003.4	1329.8	1297.0	1274.6	999.9	274.7	42.9	2	762.7	0.297158	0.513545
47	127.4	801.8	1085.8	970.2	945.2	792.0	173.2	115.6	2	600.9	0.267637	0.534617
48	132.3	745.7	1068.9	742.0	966.2	594.0	272.2	276.9	2	649.3	0.250538	0.637447
49	75.4	827.6	1267.8	1049.4	1076.6	712.3	363.8	236.4	2	570.4	0.214630	0.442926
50	117.6	.	.	.	.	.	.	.	2	.	.	.

APPENDIX A Continued

SUMMARY OF DATA OF INDIVIDUAL SITES 14:35 WEDNESDAY, AUGUST 23, 1978 24

OBS	DATE	SITE	SECON	FRP	TOTP	TFP	TSOP	MADMP	COSP	MCLP
51	JULY 5	MAUNEE/WATERVILLE	158	0.103	0.335	0.102	1436.7	266.0	432.8	132.3
52	JULY 21	SANDUSKY/BUCKEYUS	420	0.315	1.054	0.505	2419.0	421.8	310.3	76.0
53	JUNE 4	RIC CREEK	19	0.149	0.323	0.223	5222.2	980.4	1911.0	132.3
54	JUNE 6	CHAGRIN RIVER	394	0.034	0.492	0.108	1049.5	195.1	148.7	180.7
55	JUNE 6	CUYAHOGA	52	0.610	0.928	0.637	7403.8	1332.4	1465.9	179.5
56	JUNE 6	MOSKINS CREEK	46	0.058	0.152	0.063	1934.8	566.8	343.0	34.9
57	JUNE 6	MEFF RUN	38	0.013	0.555	0.177	12263.2	273.0	212.3	16.5
58	JUNE 6	MONTVILLE DITCH	78	0.010	0.854	0.310	6359.0	373.4	206.2	63.7
59	JUNE 6	GRAND RIVER	172	0.074	0.303	0.076	1392.0	222.2	191.7	99.2
60	JUNE 6	ROCKY RIVER	36	1.415	1.749	1.762	29555.6	88.6	2160.1	104.1
61	JULY 7	MUNTAID-RUN	12	0.020	0.076	0.030	4166.7	71.1	93.9	350.4
62	MAR 28	CATTARAUGUS	3602	0.138	2.954	0.170	772.9	36.1	175.6	357.7
63	APR 23	CATTARAUGUS	3666	0.016	1.199	0.044	306.9	180.1	249.1	115.2
64	APR 23	DELAWARE	292	0.024	0.479	0.050	7054.8	52.7	200.1	234.5
65	APR 23	EIGHTEEN MI CREEK	2686	0.029	1.635	0.049	501.6	76.0	130.7	271.3
66	APR 23	SOUTH CATTARAUGUS	570	0.032	0.694	0.050	1129.3			
OBS	RESIP	FRAIP	PACTP	PRSTP	WHAIP	ORGP	DIFFP	SUM	PERNA	PERTA
51	98.0	429.1	1173.4	1059.3	1113.9	272.3	119.1	698.8	0.225730	0.593007
52	137.2	951.3	1296.2	1168.2	705.4	.	.	739.1	0.330042	0.569434
53	78.4	3002.1	.	.	.	.	.	2791.4	.	.
54	58.8	633.3	808.0	732.6	574.2	131.2	75.4	393.8	0.241460	0.497376
55	107.8	3065.6	.	.	.	.	.	2798.3	.	.
56	69.6	1013.3	.	.	.	.	.	409.8	.	.
57	52.1	533.9	.	.	.	.	.	485.3	.	.
58	93.3	726.6	.	1126.1	.	.	.	579.6	.	.
59	39.2	542.2	1060.5	742.5	779.6	250.0	319.0	404.0	0.209524	0.380952
60	60.0	2412.8	.	.	.	.	.	2248.7	.	.
61	.	574.2	690.2	643.5	555.9	22.3	46.7	165.0	0.103014	0.239061
62	58.8	661.3	664.9	663.3	516.8	14.9	1.6	211.7	0.054294	0.518394
63	91.9	632.6	341.6	772.2	683.2	94.0	69.4	429.2	0.213997	0.539991
64	98.2	562.1	681.8	653.4	532.1	37.1	29.4	252.8	0.077295	0.370793
65	74.7	546.6	723.8	613.8	659.0	104.6	110.0	206.7	0.105001	0.295576
66	68.6									

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APPENDIX B

STATISTICAL ANALYSIS SYSTEM

14:35 WEDNESDAY, AUGUST 23, 1978

CORRELATION COEFFICIENTS / PAGES 3 (9) UNDER MORPHOLOGY / NUMBER OF OBSERVATIONS

	SECTION	FRP	TOTP	TSP	TSOP	WAMP	COBP	WCLP	RESIP	FRAP	PRCTP	PRSTP	WMAFP
SECTION	1.00000 0.00000 66	-0.10205 0.4149 66	0.74228 0.0001 66	-0.23052 0.0625 66	-0.30255 0.0145 65	-0.30255 0.0145 65	-0.25342 0.0572 57	0.36770 0.0026 65	-0.14534 0.2705 57	-0.25832 0.0524 57	-0.49284 0.0017 38	-0.40378 0.0044 48	-1.55166 0.0001 44
FRP	-0.10205 0.4149 66	1.00000 0.0000 66	0.31163 0.0109 66	0.46097 0.0001 65	0.09137 0.4491 65	0.39493 0.0001 57	-0.02769 0.8267 65	-0.07313 0.5828 57	0.44560 0.0005 57	0.39220 0.0149 38	0.25218 0.0764 48	0.25218 0.0764 48	0.13952 0.3499 44
TOTP	0.74228 0.0001 66	0.31163 0.0109 66	1.00000 0.0000 66	0.12771 0.3063 66	-0.20557 0.0987 65	-0.07150 0.5971 57	0.12219 0.3322 65	-0.29544 0.0314 57	-0.14144 0.2940 57	-0.27270 0.0976 38	-0.30154 0.2373 48	-0.30154 0.2373 48	-0.41603 0.0049 44
TSP	-0.23052 0.0625 66	0.46097 0.0001 65	0.12771 0.3063 66	1.00000 0.0000 66	0.07029 0.5779 65	-0.09359 0.5050 65	-0.07313 0.5828 57	-0.10196 0.4505 57	0.40457 0.0018 57	0.46400 0.0033 35	0.23463 0.1984 48	0.23463 0.1984 48	0.20898 0.1734 44
WAMP	-0.30255 0.0145 65	0.09137 0.4491 65	-0.07313 0.5828 57	0.44560 0.0005 57	0.39220 0.0149 38	0.25218 0.0764 48	0.25218 0.0764 48	0.13952 0.3499 44	0.44560 0.0005 57	0.39220 0.0149 38	0.25218 0.0764 48	0.25218 0.0764 48	0.13952 0.3499 44
COBP	-0.25342 0.0572 57	0.59493 0.0001 57	-0.02769 0.8267 65	-0.07313 0.5828 57	0.39493 0.0001 57	1.00000 0.0000 57	0.01553 0.27003 57	0.41922 0.0012 57	0.77022 0.0001 57	0.86369 0.0001 38	0.64391 0.2001 48	0.64391 0.2001 48	0.74329 0.0001 44
WCLP	0.36770 0.0026 65	0.0026 0.8267 65	0.0026 0.8267 65	0.0026 0.8267 65	0.0026 0.8267 65	0.0026 0.8267 65	0.0026 0.8267 65	0.0026 0.8267 65	0.0026 0.8267 65	0.0026 0.8267 65	0.0026 0.8267 65	0.0026 0.8267 65	0.0026 0.8267 65
RESIP	-0.14534 0.2705 57	-0.25832 0.0524 57	-0.49284 0.0017 38	-0.40378 0.0044 48	-1.55166 0.0001 44	-0.30154 0.2373 48	-0.30154 0.2373 48	-0.41603 0.0049 44	-0.44560 0.0005 57	-0.39220 0.0149 38	-0.25218 0.0764 48	-0.25218 0.0764 48	-0.13952 0.3499 44
FRAP	-0.25832 0.0524 57	0.44560 0.0005 57	0.39220 0.0149 38	0.25218 0.0764 48	0.25218 0.0764 48	0.13952 0.3499 44	0.13952 0.3499 44	0.44560 0.0005 57	0.39220 0.0149 38	0.25218 0.0764 48	0.25218 0.0764 48	0.13952 0.3499 44	0.13952 0.3499 44
PRCTP	-0.49284 0.0017 38	0.0017 0.8267 65	0.0017 0.8267 65	0.0017 0.8267 65	0.0017 0.8267 65	0.0017 0.8267 65	0.0017 0.8267 65	0.0017 0.8267 65	0.0017 0.8267 65	0.0017 0.8267 65	0.0017 0.8267 65	0.0017 0.8267 65	0.0017 0.8267 65
PRSTP	-0.40378 0.0044 48	0.25218 0.0764 48	-0.30154 0.2373 48	-0.30154 0.2373 48	-0.41603 0.0049 44	-0.44560 0.0005 57	-0.39220 0.0149 38	-0.25218 0.0764 48	-0.25218 0.0764 48	-0.13952 0.3499 44	-0.13952 0.3499 44	-0.13952 0.3499 44	-0.13952 0.3499 44

APPENDIX B Continued

S T A T I S T I C A L A N A L Y S I S S Y S T E M

14:35 WEDNESDAY, AUGUST 23, 1978

CORRELATION COEFFICIENTS / P409 > IRJ UNDER MO:RMO=0 / NUMBER OF OBSERVATIONS

	SEDCO	FRP	TOTP	TFP	TSERP	NRMP	COBP	MCLP	RESIP	FRAP	PRCTP	PRSTP	NRATP
NRATP	-0.5518	0.1392	-0.4169	0.2094	0.2324	0.7424	0.4947	-0.1631	0.2191	0.6943	0.2954	0.8286	1.0000
	0.0001	0.3694	0.0049	0.1734	0.1281	0.0031	0.0014	0.2901	0.1814	0.0001	0.2001	0.0001	0.0000
	44	44	44	44	44	44	39	44	39	39	38	44	44
NRATP	-0.3085	0.0257	-0.2267	0.2517	0.1605	0.3213	0.6052	-0.1024	0.4470	0.6954	0.4307	0.5780	0.4437
	0.0455	0.3700	0.1437	0.7913	0.3634	0.0124	0.0001	0.3124	0.0931	0.0001	0.3078	0.3001	0.0001
	43	43	43	43	43	43	38	43	39	38	37	43	43
COBP	-0.5242	0.2144	-0.3721	0.4652	0.2294	0.5544	0.0975	-0.3944	-0.2054	0.2943	0.5573	0.4580	0.4719
	0.0007	0.3906	0.0205	0.0033	0.1654	0.0001	0.5714	0.0137	0.9750	0.0802	0.0006	0.0040	0.0001
	38	38	38	38	38	38	36	38	36	36	34	38	38
DIFFP	-0.1789	0.0805	0.0212	0.3245	0.0494	0.3642	-0.1179	-0.4507	-0.1160	-0.0594	0.4516	-0.0472	0.1397
	0.2549	0.6358	0.5935	0.0163	0.7713	0.6472	0.5291	0.0051	0.5136	0.7384	0.0050	0.7814	0.4096
	37	37	37	37	37	37	34	37	34	34	37	37	37
LOC	0.5291	0.1420	0.5167	0.1347	0.0780	-0.0587	-0.0312	0.0912	-0.2969	-0.0672	-0.5105	-0.4521	-0.5791
	0.6001	0.2480	0.3001	0.2809	0.5332	0.4424	0.8174	0.4852	0.0304	0.6177	0.0011	0.0013	0.0001
	66	66	66	66	66	65	57	65	57	57	38	48	44
SUM	-0.3085	0.4537	-0.1409	0.4364	0.5227	0.7507	0.9428	-0.0701	0.3628	0.9881	0.8287	0.8290	0.7857
	0.0197	0.0002	0.2553	0.0007	0.0001	0.0001	0.0001	0.6022	0.0055	0.0001	0.0001	0.0001	0.0001
	57	57	57	57	57	57	57	57	57	57	35	42	39
PERNA	-0.4954	0.2874	-0.1931	0.4208	0.2506	0.9105	0.1431	-0.5186	0.0651	0.5156	0.7064	0.6244	0.8950
	0.0016	0.0801	0.2434	0.0085	0.1290	0.0001	0.4092	0.0009	0.7101	0.0015	0.0001	0.0001	0.0001
	38	38	38	38	38	38	35	38	35	35	32	38	38
PERTA	-0.5500	0.1699	-0.3307	0.3481	0.1693	0.5533	0.7857	-0.4104	0.2107	0.6768	0.3964	0.5003	0.4752
	0.0006	0.3242	0.0212	0.0404	0.3307	0.0006	0.0001	0.0143	0.2239	0.0001	0.0184	0.0022	0.0038
	35	35	35	35	35	35	35	35	35	35	35	35	35

	SEDCO	FRP	TOTP	TFP	TSERP	NRMP	COBP	MCLP	RESIP	FRAP	PRCTP	PRSTP	NRATP
SEDCO	-0.3085	-0.5244	-0.1769	0.5791	-0.3085	-0.4950	-0.5500						
	0.0456	0.0007	0.2949	0.0001	0.0197	0.0016	0.0006						
	43	39	37	66	57	38	35						
FRP	0.0257	0.3194	0.0805	0.1442	0.4687	0.2174	0.1699						
	0.8700	0.0506	0.6358	0.2480	0.0002	0.0001	0.3292						
	43	38	37	66	57	38	35						
TOTP	-0.2267	-0.3743	0.0212	0.5167	-0.1409	-0.1931	-0.3807						
	0.1437	0.0206	0.3955	0.0001	0.2953	0.2434	0.0212						
	43	39	37	66	57	38	35						
TFP	0.2415	0.4642	0.3924	0.1347	0.4364	0.4708	0.3481						
	0.7913	0.0033	0.0163	0.2809	0.0007	0.0095	0.0404						
	43	38	37	66	57	38	35						

APPENDIX B Continued

STATISTICAL ANALYSIS SYSTEM

14:35 WEDNESDAY, AUGUST 23, 1978

CORRELATION COEFFICIENTS / PR23 > IRI UNDER HOIRMO=0 / NUMBER OF OBSERVATIONS

	YMAIP	CRGP	DIFFP	LCC	SU4	PERNA	PERTA
YSEDP	0.16065 0.3034 43	0.22959 0.1654 38	0.04945 0.7713 37	0.07507 0.5332 66	0.52277 0.0071 57	0.25066 0.1290 37	0.16953 0.3300 35
YACMP	0.37813 0.0124 43	0.39466 0.3001 39	0.30412 0.0572 37	-0.08867 0.4824 65	0.79073 0.0001 57	0.95105 0.0001 36	0.55351 0.0006 35
CDSP	0.60523 0.0201 38	0.09756 0.5714 34	-0.11179 0.5291 34	-0.03127 0.9174 57	0.94294 0.0001 57	0.14431 0.4032 35	0.79375 0.0001 35
HCLP	-0.10241 0.5126 43	-0.39640 0.0137 38	-0.45071 0.0051 37	0.08812 0.4852 65	-0.07051 0.6022 57	-0.51940 0.0209 39	-0.41347 0.0143 35
RESIP	0.46704 0.0231 38	-0.00541 0.9750 36	-0.11600 0.5136 34	-0.28696 0.0304 57	0.34221 0.0055 57	0.04512 0.7101 35	0.21097 0.2239 35
FRAIP	0.68554 0.6001 38	0.29436 0.0809 36	-0.02944 0.7384 34	-0.06752 0.6177 57	0.98818 0.0001 57	0.51565 0.0015 35	0.67609 0.0001 35
PRCTP	0.43077 0.0078 37	0.55573 0.0006 34	0.45161 0.0050 37	-0.51065 0.0011 32	0.92997 0.0001 35	0.70649 0.0001 39	0.39641 0.2194 35
PRSTP	0.57826 0.0001 43	0.45580 0.0040 32	-0.04720 0.7814 37	-0.45213 0.0013 45	0.82390 0.0001 42	0.65440 0.0001 35	0.50003 0.0022 35
MAATP	0.64637 0.0001 43	0.64713 0.0001 32	0.13970 0.4096 37	-0.57911 0.0001 44	0.79457 0.0001 39	0.62567 0.0001 32	0.47652 0.0038 35
MAAIP	1.00000 0.0000 43	0.10713 0.5220 52	0.04167 0.7169 37	-0.26588 0.0849 43	0.70294 0.0001 33	0.32705 0.0482 37	0.42171 0.0130 34
CRGP	0.10713 0.5420 33	1.00000 0.3000 32	0.15903 0.3690 34	-0.62108 0.0001 38	0.48235 0.0029 36	0.51736 0.0004 34	0.32460 0.0653 33
DIFFP	0.04167 0.7169 37	0.15903 0.3690 34	1.00000 0.0000 37	-0.06770 0.6905 37	0.21139 0.2301 34	0.22449 0.1624 37	-0.08936 0.6153 34
LCC	-0.10241 0.0348 43	-0.39640 0.0001 38	-0.45071 0.0051 37	0.08812 0.0000 66	-0.07051 0.6022 57	-0.51940 0.0209 39	-0.41347 0.0143 35

APPENDIX B Continued

S T A T I S T I C A L A N A L Y S I S S Y S T E M

14335 WEDNESDAY, AUGUST 23, 1972

CORRELATION COEFFICIENTS / FROM > [R] UNDER MO:MMO=0 / NUMBER OF OBSERVATIONS

	MMAP	ORGP	DIFFP	LOC	SUM	PIKMA	PERTA
SUM	0.70294	0.49235	0.21135	-0.06215	1.00000	0.76927	0.92731
	0.0021	0.0029	0.2301	0.6461	0.0000	0.0001	0.0001
	38	36	34	57	57	35	35
PERMA	0.32706	0.57736	0.23448	-0.42364	0.76327	1.00000	0.60000
	0.0482	0.0004	0.1524	0.0077	0.0001	0.0000	0.0001
	37	34	37	38	35	38	35
PERTA	0.42171	0.32460	-0.02936	-0.53536	0.92731	0.60000	1.00000
	0.0150	0.0053	0.6153	0.0009	0.0001	0.0001	0.0000
	34	33	34	35	35	35	35